



Using Forests to Enhance Resilience to Climate Change

Aaron Russell, Bruno Locatelli, Emilia Pramova, Godfrey Jeff Alumai, Diji Chandrasekharan

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NOVEMBER 2012

WORKING PAPER

Using Forests to Enhance Resilience to Climate Change

What do we know about how forests can contribute to
adaptation?



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EXECUTIVE SUMMARY

The Intergovernmental Panel on Climate Change (IPCC) has gathered substantial evidence on current and projected impacts of climate change across geographies, ecosystems, and sectors. Even under the most stringent mitigation scenarios, the world's temperature will continue to increase, rendering adaptation strategies a necessity for long-term local and national planning.

A focus on long-term adaptation strategies must not, however, eclipse the need to address severe challenges posed by current, aggravated climate variability. Although there are significant sub-regional differences, rainfall in Africa has declined over the past half century and drought events are manifesting a trend of heightened annual and seasonal variability. Southeast Asia has endured climate extremes that include monsoons, tropical cyclones, El Niño/La Niña-Southern Oscillation events, extreme variability in rainfall, and very high temperatures. Future climate change, coupled with a variety of anthropogenic pressures on ecosystems (for example, deforestation due to land conversion, pollution, or human development in floodplains), will only exacerbate these effects.

Human activity is having a significant and, at times, escalating impact on the world's ecosystems and their ability to provide those critical services that are becoming increasingly important for societal adaptation to climate change. Unsustainable logging and agricultural practices in areas with significant gradients, for example, make it possible for intensification of hurricanes or extreme rainfall events to result in disastrous flooding and landslides. In other contexts, anthropogenic impacts are mixed. Some land use changes may combine with increased periods of drought to facilitate large-scale transitions between ecological forms (ex. from savannah to desert or from humid to dry forest system). In others, agricultural intensification combined with out-migration to cities and/or conservation policies may actually result in increased/maintained tree cover and agricultural productivity despite decreases in rainfall.

Forest ecosystems provide human societies with a wide range of provisioning (for example, wood and non-timber forest products) and regulating services (for example, base flow and storm flow regulation) that reduce vulnerability at the local and sectoral levels. Ecosystem-based adaptation (EBA) is a useful approach for conserving these ecosystem services and reducing vulnerability, because it encompasses adaptation strategies that explicitly value the roles of ecosystem services in adaptation to climate change across sectors and scales. Ecosystem-based adaptation strategies can be cost-effective and sustainable, and generate a wide range of environmental, social, economic, and cultural benefits. Furthermore, EBA has the potential to address both the immediate needs of society and those necessary to prepare for future hazards, and would be a useful conceptual framework for helping to develop “triple-win” climate-smart agriculture approaches.

Effective use of EBA strategies requires (1) sustainable management and adaptation of forest ecosystems in order to (2) ensure their roles in facilitating the adaptation of people and sectors. This is necessary because land use pressures coupled with climate change will have significant impacts on forest growth, species diversity, and critical functions that underpin the delivery of services. At present, sectors most dependent on forest ecosystem services have little incentive to invest in forest adaptation.

Mainstreaming forests into the adaptation policies of other sectors requires cross-scale (local to national, and ideally international) and cross-sectoral approaches, because ecosystem benefits and management costs generally occur in different locations and in different sectors of society. This will require a greater understanding of how forest ecosystems reduce other sectors' vulnerability to climate change, and how management of forest ecosystems in certain landscapes can assist with adaptation of forest systems. Implementation of EBA will require adapting and developing institutional arrangements to support cross-sectoral approaches and providing necessary incentives.

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1. Introduction

The global dialogue surrounding the United Nations Framework Convention for Climate Change has focused on two strategies for addressing challenges associated with climate change: (1) mitigation (reducing the accumulation of greenhouse gases (GHG) in the atmosphere) and (2) adaptation (reducing the vulnerability of societies and ecosystems to the impacts of climate change). Forests feature in both of these strategies. The role of forests as stores of carbon and therefore in reducing GHG emissions has been captured in the efforts associated with reducing emissions from deforestation and degradation and enhancing carbon stocks (REDD+). In the area of adaptation, forests have featured less prominently. Only a few National Adaptation Programs for Action (NAPAs) mention the need to adapt forest systems to changing climates. The low profile of forests in the adaptation discussion is surprising, largely because the role of forests in generating services is widely accepted.

In the arena of adaptation, there are two ways forests and adaptation can be linked:

1. Forests can be used to strengthen societal adaptation to climate change as they provide critical ecosystem services, such as wood, non-timber forest products, and watershed hydrological regulation, the values of which are usually underestimated by society (“Forests for Adaptation”).
2. Forests structures, species, and species distribution are being modified by climate change. Responding to this requires adaptation of forests themselves in order to prevent a degradation of forest resources and to protect the ecosystem services that society relies on for its adaptation (“Adaptation for Forests”).

Adapting forests to climate change has been the focus of a fair amount of work in the forest sector. A comprehensive piece in this area was the International Union of Forest Research Organizations 2009 publication *Adaptation of Forests and People to Climate Change – A Global Assessment*. This work identifies possible changes in forest ecosystems due to climate change. It also documents how varied the response of forests systems to climate change may be. The report points to the limited knowledge available to effectively comprehend how forests will respond to climate change, and advocates strengthening the ability of institutions to deliver on sustainable forest management, which will help with the resilience of forest systems.

Forests can play an important role in adapting to climate change. Many of the provisioning services (for example, wood, fuel, fodder, non-timber forest products), regulating services (for example, of water, of soil erosion, microclimate), and supporting services (for example, nutrient cycling and primary production) that forests provide can contribute to reducing the vulnerability of systems to climate change, and as a result enhance their resilience. There is knowledge about when forests contribute these services, and where they are beneficial. In some cases there is also information regarding how the use of forests compares to an alternative source of the same services.

This working paper presents a review of relevant work on forests and the services they provide, and the use of forests and trees in adaptation. The paper starts with a brief discussion about climate change. It also provides a conceptualization of how to link forest services with their use for adaptation (more specifically, ecosystem-based adaptation).

2. Climate Change

2.1 What will our climate look like in the future?

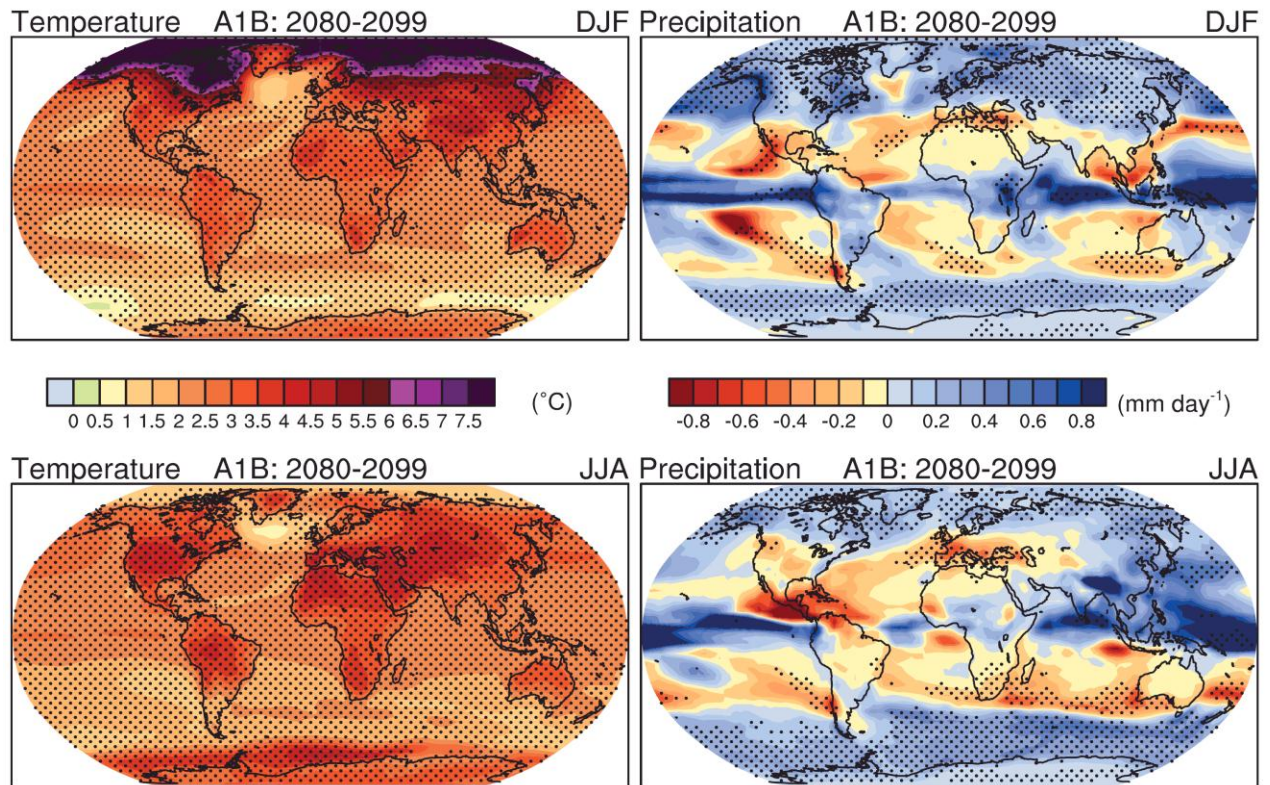
The analysis of historical land and sea surface temperature records dating from 1850 demonstrates a clear trend of global average temperatures increasing $0.76^{\circ}\text{C} \pm 0.19^{\circ}\text{C}$ (Brohan et al. 2006). The IPCC Fourth Assessment Report (IPCC 2007b) concluded that this was *very likely* caused by increased concentrations of anthropogenic greenhouse gases in the atmosphere. Irrespective of any mitigation policies implemented, current rates of net GHG emissions will ensure that mean global surface temperatures will continue to rise by roughly 0.2°C per decade through 2020 (IPCC 2007b).

However, climate projections for the rest of the 21st century require certain assumptions to be made about future socioeconomic trends, GHG emissions, and mitigation policies, and consequently it is prudent to think of the future in terms of a range of scenarios. Relative to mean temperatures at the end of the 20th century, global surface temperatures are expected to rise by roughly 1.8°C over the next 100 years according to the IPCC's low emissions scenario "B1," or by 4.0°C according to the high emissions scenario "A1FI" (IPCC 2007b).¹ Similarly, global sea levels are expected to rise by 0.26–0.59 meters (for scenario A1FI) or 0.18–0.38 meters (for scenario B1), and all models predict average increases in global precipitation (IPCC 2007b). Given the challenges that the international community has had in adopting binding emission-reduction levels, some authors have recommended that adaptation strategies should prepare for net global warming (over the next century) at a *minimum* of 3°C (van Vuuren et al. 2011).

The projected mean global values presented above mask great spatial and seasonal variation in local and regional climate predictions and consequent impacts. Figure 1 shows the spatial distributions of predicted surface temperature and precipitation during December–February and June–August under emissions scenario A1.

¹ A1FI and B1 are scenarios from the IPCC Special Report on Emission Scenarios (SRES) (2000). There are many such scenarios, which are grouped into six designations that are commonly used as markers, from the highest to the lowest emission scenarios: A1FI, A1T, A1B, A2, B1, and B2.

Figure 1. Mean Changes in Surface Air Temperature (°C, left) and Precipitation (mm day⁻¹, right) for Boreal Winter (DJF, top) and Summer (JJA, bottom) for the 21st Century



Source: Meehl et al. 2007.

The predicted impacts of climate change in different sub-regions of Asia, Latin America, and Africa have been summarized by Christensen et. al (2007) in the table below.

Table 1. Climate Change Trends in Three Continents, According to IPCC

<i>Variable</i>	<i>Specific continents, regions, and locations</i>	<i>Confidence</i>	<i>Trend</i>
Africa			
Temp	Throughout the continent	Very likely	Warming larger than the global annual mean warming in all seasons
Temp	Drier subtropical regions	Very likely	Warming more than the moister tropics
Prec	Much of Mediterranean Africa and the northern Sahara	Likely	Decrease in annual rainfall
Prec	Southern Africa	Likely	Decrease in rainfall in much of the winter rainfall region and western margin
Prec	East Africa	Likely	Increase in annual mean rainfall
Prec	The Sahel, the Guinean Coast, and the southern Sahara	Unclear	Unclear trends in precipitation
Asia			
Temp	Central Asia, the Tibetan Plateau, and northern Asia	Likely	Warming well above the global mean
Temp	Eastern Asia and South Asia	Likely	Warming above the global mean
Temp	Southeast Asia	Likely	Warming similar to the global mean
Prec	Northern Asia and the Tibetan Plateau	Very likely	Increase in precipitation during boreal winter
Prec	Eastern Asia and southern parts of Southeast Asia	Likely	Increase in precipitation during boreal winter
Prec	Northern, East, South Asia, most of Southeast Asia	Likely	Increase in precipitation in summer
Prec	Central Asia	Likely	Decrease in precipitation in summer
Extr	East Asia	Very likely	Heat waves/hot spells of longer duration, more intense and more frequent
Extr	Parts of South Asia, and in East Asia	Very likely	Increase in the frequency of intense precipitation events
Extr	East Asia, Southeast Asia, and South Asia	Likely	Increase in extreme rainfall and winds associated with tropical cyclones
Central and South America			
Temp	Southern South America	Likely	Warming similar to the global mean warming
Temp	All areas except southern South America	Likely	Warming larger than the global mean warming
Prec	Most of Central America and in the southern Andes	Likely	Decrease in annual precipitation (with large local variability in precipitation response in mountainous areas)
Prec	Tierra del Fuego	Likely	Increase in winter precipitation
Prec	Southeastern South America	Likely	Increase in summer precipitation
Prec	Northern South America, including the Amazon forest	Unclear	Unclear trends in annual and seasonal mean rainfall, but qualitative consistency in Ecuador and northern Peru (increasing rainfall) and at the northern tip of the continent and in southern northeast Brazil (decreasing)

Source: Christensen et al. (2007).

Note: Prec= precipitation, Temp= temperature, Extr= extreme events.

2.2 What signs of climate change are we already observing?

While there is some uncertainty regarding the specific extent to which climate will change in different parts of the globe in the coming decades, many regions of the world are already having to address trends of aggravated climate variability (such as increased frequency of droughts and storms and more erratic or intense rainfall patterns), which are thought to represent the initial impacts of climate change (IPCC AR4, 2007).

A typical example of aggravated climate variability that is thought to be a result of climate change is the increased frequency of “El Niño” or El Niño/La Niña-Southern Oscillation (ENSO) events during the past few decades (Qiong et al. 2008). ENSO events have been causing significant climate hazards in Central and South America, where such events have become more intense and frequent since the mid-1970s (Poveda, Waylen, and Pulwarty, et al., 2006).

However, through the interconnectedness of global weather systems, ENSO events can result in extreme weather events (such as floods and droughts) in many regions of the world.

Similarly, annual rainfall in the African Sahel declined by 25–30 percent between 1960 and 2000. Global climate change scenarios predict that this trend will continue through 2050 (Mortimore 2010).

Southeast Asia has also experienced a range of climate extremes during the recent decades, including overall declines in rainfall, extreme variability in intra-annual rainfall patterns, increased frequency of heat waves, and increased frequency of tropical cyclones (ADB 2009).

It is clear that even though there are many uncertainties related to climate change, aggravated climate variability is occurring now and is projected to increase in the future with increasingly severe impacts on both ecosystems and societies.

2.3 How will climate change impact key ecosystems?

The IPCC (2007a) report observes current, and predicts a range of future, climate change impacts on people and ecosystems across six main interrelated areas: fresh water; ecosystems; food, fiber, and forest products; coastal and low-lying areas; industry and settlements; and health. It must be noted that the physical and ecological data on which the IPCC report is based is strongly skewed toward developed countries, highlighting the need for more research on the likely impacts of climate change on developing country ecological systems. A summary of key impacts on terrestrial and coastal systems are presented here.

Terrestrial ecosystems are being affected with earlier timing of spring events and shifts in the ranges of plant and animal species, leading to diverse impacts across sectors, such as the spread of insect pests, disease vectors, and increasing uncertainty in the agricultural cropping cycle. Warmer and drier conditions have led to a reduced length of growing seasons with severe effects on food security, as well as increased frequency and intensity of fire. Sea-level rise, coupled with other drivers of coastal land-use change, is already contributing to losses of coastal wetlands and mangroves, leading to increased damage from extreme events and consequent coastal erosion and flooding in many areas.

By mid-century, annual average river runoff and water availability are projected to increase by 10–40 percent at high latitudes and in wet tropical areas, and decrease by 10–30 percent over some dry regions at mid-latitudes and in the dry tropics, areas that are already under conditions of water stress. As an illustration, in Africa, between 75 and 250 million people are projected to experience increased water stress by 2020. Drought-affected areas will likely expand while simultaneously being affected by an increased magnitude and frequency of heavy precipitation events, leading to greater risks from flood-related disasters.

The resilience of many ecosystems is likely to be strained by an unprecedented combination of climate change, associated disturbances, and anthropogenic drivers of change. Approximately 20–30 percent of the world's plant and animal species will be under increased risk of extinction. Some of these species and ecological communities may be able to survive through shifts in their distribution (by latitude, by altitude, or regionally), however this will largely depend on the availability of biological corridors (for example, requiring decreased forest fragmentation and increased connectivity) and their ability to compete with other species, both native and invasive.

If global temperature averages increase beyond the 1.5–2.5°C threshold, many ecosystems are projected to reach ecological tipping points, resulting in major changes in structure and function and the ecological interactions

underpinning vital ecosystem services for humanity. This may result in transitions between different forest types (from dense humid forests to open dry forests, dry forests to savannahs, savannahs to deserts) that will significantly impact the provision and regulation of hydrological services at the local, national, and regional levels. In South and Central America, for example, increased temperature and an associated decrease in water retained in the soil are projected to lead to gradual replacement of tropical forest by savannah. Projected impacts on forest ecosystems are described in more detail below.

Even though crop productivity is projected to increase slightly at mid- to high latitudes, at lower latitudes, especially in seasonally dry and tropical regions, crop productivity is expected to decrease for even small local temperature increases (1–2°C). Overall agricultural production will come under pressure due to a combination of decreased availability of water at key times during the cropping cycle, increased temperatures that further reduce water demands through increased evapotranspiration, and increased frequency of floods, droughts, and crop diseases. In some areas, the timing and distribution of precipitation may be altered, forcing a shortening of the cropping cycle, or a shift to new cropping systems altogether, such as if a uni-modal rainy season becomes bi-modal.

Coastal areas will be exposed to an increased frequency and severity of risks, including coastal erosion and sea-level rise, which will negatively affect coastal wetland ecosystems, especially in areas where they are already degraded or are constrained to migrate horizontally or adapt vertically. Flood hazards are projected to affect millions of people in low-lying areas due to sea-level rise but also to increased precipitation events by the 2080s, especially in Southeast Asia where people already face other challenges, such as tropical storms and coastal subsidence.

The health of millions of people is projected to be affected due to increased food insecurity and malnutrition; increased deaths, disease, and injury due to heat waves, floods, storms, fires, and droughts; and increased burden of water-borne and vector-borne diseases.

2.4 Some sectoral impacts of climate change for which adaptation is needed

In agriculture, overall there is an expected decrease in crop yields in developing countries (although this varies greatly between countries) (Perry et al., 2004). Reduced soil moisture and evapotranspiration are likely to increase land degradation, salinization, and desertification in some areas. Some of the on-site effects of erosion and salinization in turn are expected to translate into lower crop yields and livestock productivity. For Africa, yields from rain-fed crops could be halved by 2020 in some countries, and already compromised fish stocks will be depleted further due to rising water temperature. Inundation of coastal zones and coastal deltas, erosion, negative impacts on fish stock and availability of water, and degradation of marine ecosystems are anticipated due to extreme weather events.

The water resource sector will be significantly affected by climate change. In Latin America, Asia, and Africa, increasing water stress is a concern for hundreds of millions of people. Decreased availability of fresh water in large river basins of Asia, decreased runoff due to loss and retreat of glaciers, and overall water shortage will be a constraint that will need to be addressed. Erosion from severe rainfall and from wind will also affect water. Movement of sediment and the associated agricultural pollutants will affect bodies of water. Some of the anticipated impacts are increased sedimentation of canals, water channels and dams, and contamination of drinking water. The eroded soil also has a lower capacity to absorb water, which in turn increases runoff and has associated downstream damages.

Water is central to the energy sector. Climate change impacts on the energy sector can stem from decreased availability of water for hydropower generation, reduced availability of water for cooling power generators, and

changed in temperature and pressure patterns affecting wind and solar power generation (Contretas-Lisperguer and de Cuba 2008).

2.5 Interactions between climate change and anthropogenic drivers of change

The Millennium Ecosystem Assessment concluded that human activity is having a significant and escalating impact on the world's ecosystems and their ability to provide services, aggravating the adverse impacts of other drivers of change such as climate change (MEA 2005).

It should be reemphasized that changes in climate may not always be the most significant driver of landscape level change. In many cases, the negative impacts of climate change will be compounded by societal decisions regarding forest governance and land-use/coastal zone planning. Therefore, the incremental increases in temperature or rainfall may result in unpredictable and sudden, dramatic changes in ecological systems' structure and function and landscape transformations.

3. Vulnerability and Climate Change Adaptation

3.1 Understanding vulnerability and resilience to climate change

The concepts of resilience and vulnerability are embedded within many discussions on climate change adaptation.

From a socioecological system perspective, resilience is characterized by the amount of change that the system can undergo and still retain a desired function and structure, the degree to which the system is capable of self-organization, and the system's ability to build and increase its capacity for learning and adaptation (Gunderson and Holling 2002; Walker et al. 2006).²

Many classical approaches to the management of terrestrial resources are based on the assumption that environmental variability could be controlled in order to maximize harvests of key species of commercial value. However, C.S. Holling (1973 and 1978) and the growing community of practice around resilience and adaptive management have transformed the ways in which resource scientists and managers think about forest management and environmental change. The adaptive management approach is founded upon a resilience-based understanding of ecological function and change. It is based on the notion that change is episodic rather than gradual and continuous. At a certain scale, the spatial organization of a system is patchy and there are non-linear processes among different spatial scales. The adaptive management approach also values variability and finds that destabilizing forces are needed to maintain structure and diversity, while stabilizing forests help maintain productivity (Holling 1973 and 1978; Holling and Meffe 1996; Holling and Sanderson 1996).

Maintaining an ecosystem's capacity to change and reorganize through the same identity and to absorb sudden shocks is of critical importance (Folke 2002; Holling 1973 and 1978; Berkes and Folke 1998). Controlling environmental variability helps achieve short-term stability, but tends to increase ecosystem vulnerabilities to large shocks, with the potential of causing ecosystems to undergo sudden and unpredictable transformations in structure and function (Holling 1973 and 1978; Holling and Sanderson 1996; Berkes and Folke 1998). Of particular concern are policies that disrupt natural cycles of flooding, drought, and fire; or that significantly alter trophic interactions (Gunderson and Holling 2002; Gunderson et al. 2006).

² See also Resilience Alliance 2001: www.resalliance.org.

The resilience concept is very useful for understanding the types of management that undermine ecosystem adaptation. However, the difficulties in identifying benchmarks for resilience (for example, a requisite level of structural diversity, frequency/magnitude of variation) for most socioeconomic systems make resilience less useful as an analytical tool in climate change adaptation research. Instead, we focus here on a proxy for a roughly opposite condition that we can measure more easily based on currently available data: vulnerability.

The IPCC approach for understanding vulnerability

The concept of vulnerability is more of an operational concept. Due to its applications in an array of disaster relief, livelihood development, health management, climate change, psychology, and risk management (etc.) settings, vulnerability has been defined differently by practitioners and researchers, and has frequently been related to concepts of risk, hazard, sensitivity, exposure, adaptive capacity, resilience, and potential impacts (Brooks 2003; Eakin and Luers, 2006). We apply the definition for vulnerability proposed by the IPCC, which is now widely accepted within the climate change community (see Metzger, Leemans, and Schröter 2005):

the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity. (McCarthy et al. 2001, p.995)

Notably, as discussed by Füssel (2007a), the IPCC approach to analyzing vulnerability integrates assessments of external factors (exposure) and internal factors (sensitivity and adaptive capacity), and considers both socioeconomic and biophysical factors (see Table 2).

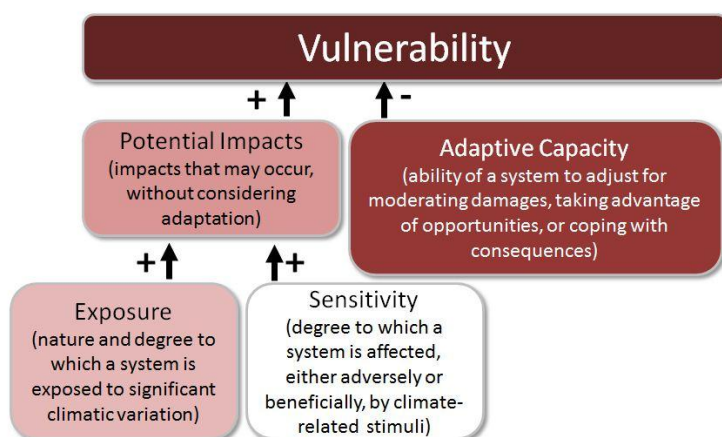
Table 2. Factors Contributing to Vulnerability

	Socioeconomic	Biophysical
Internal	Household income, social networks, access to information	Topography, environmental conditions, land cover
External	National policies, international aid, economic globalization	Severe storms, earthquakes, sea level change

Source: Füssel (2007a).

The relationships between the primary components of vulnerability (exposure, sensitivity, and adaptive capacity) are illustrated in Figure 2.

Figure 2. The Components of Vulnerability



Source: Definitions are from IPCC: McCarthy et al. (2001).

Note: The signs under the arrows mean that high exposure, high sensitivity, and low adaptive capacity induce high vulnerability.

The components of vulnerability

Based on the IPCC definition of vulnerability, exposure is external to the system, while sensitivity and adaptive capacity are internal.

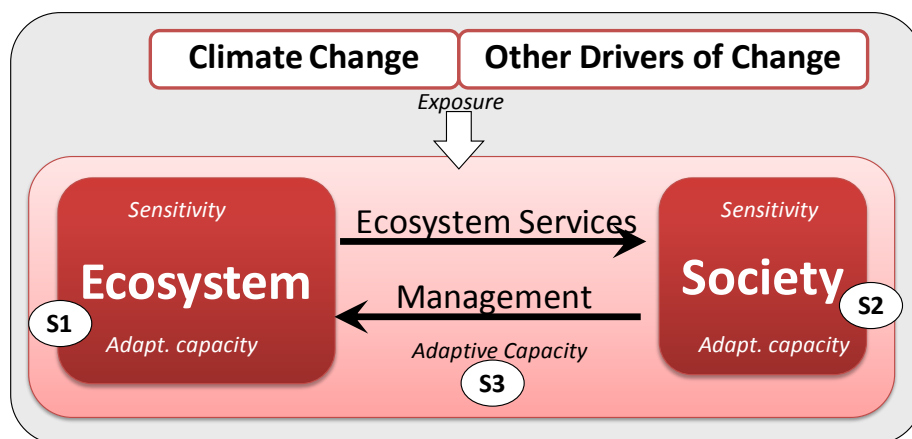
Using the example of a hypothetical study related to the vulnerability of forest growth to changes in temperature regimes, the primary variables of exposure might relate to the projected average number of peak temperature days per year, and the projected rainfall for those same periods. In some studies, ecosystem variables such as watershed hydrological response may also be relevant, as might socioeconomic variables (for example, globalization of markets or development assistance) (see O'Brien et al. 2004). As mentioned, sensitivity is a characteristic of the system itself and represents the “dose–response” relationships between the exposure and the effects (that is, sensitivity of tree dynamics to temperature, sensitivity to intensity of wildfires, sensitivity to rainfall). Together, exposure and sensitivity represent the potential impact of climate change on a specific socioecological system (that is, the likelihood of a forest ecosystem and watershed undergoing significant changes due to species loss, forest fires, erosion, etc.). Finally, adaptive capacity is the system’s internal ability to modify its characteristics in response to potential climate change impacts. This might relate to the system’s ability to continue to provide key ecosystem services through a reorganization of species composition.

Based on work conducted by Turner et al. (2003) and Metzger, Leemans, and Schröter (2005), CIFOR (Center for International Forestry Research and CATIE (Tropical Agricultural Research and Higher Education Center) developed a general framework for the assessment of vulnerability in coupled socioecological systems.³ This approach has been applied to the analysis of vulnerability and design of adaptation strategies in diverse ecosystem services and

³ By the TroFCCA project (CIFOR–CATIE, www.cifor.cgiar.org/trofcca).

different contexts, such as non-timber forest products in West Africa and forest hydrological services in Central America (see Figure 3).

Figure 3. Three Types of Vulnerabilities



Source: TroFCCA project.

Within this model, three main sets of vulnerability criteria (labeled S1-S3) are defined.

The first set (S1) describes the vulnerability of ecosystem services to climate change or variability and other threats. This may include criteria related to exposure and sensitivity to climate change or variability; and ecosystem adaptive capacity as a function of current degradation or other pressures.

The second set (S2) deals with the human system and its vulnerability to the loss of ecosystem services. The sensitivity of the system (for example dependence on non-timber forest products or clean water) and its adaptive capacity (for example availability of substitutes for the lost services) can be used as criteria. For this set, the external drivers of changes must also be taken into account, for example macroeconomic policies or energy prices.

The third set (S3) considers the adaptive capacity of the system as a whole. It refers to the capacity of the human systems to reduce the loss of ecosystem services. Criteria can refer to the capacity of reducing “maladaptation” practices (for example removing practices that increase pressures on ecosystems) and the capacity to implement forest adaptation.

3.2 From vulnerability to adaptation

An analysis of system vulnerability provides the basic framework for climate change adaptation (Adger, Arnell, and Tompkins 2005):

- **Reduce Exposure:** for example, by relocating a community from a flood-prone area or implementing an emergency alert system.
- **Reduce Sensitivity:** for example, by planting new crops resistant to drought or creating construction norms for building in hazard-prone areas.
- **Increase Adaptive Capacity:** for example, by raising population education or designing insurance schemes.

There are many examples of spontaneous adaptation to climate change demonstrated by diverse communities (see Mortimore and Adams, 2001; Orlove, 2005). However, such efforts, as they rely exclusively on existing institutions and norms, are unlikely to enable societies to cope with the projected unprecedented rates of change and cumulative impacts. Future adaptation will require “deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state” (McCarthy et al. 2001, p.982).

Many rural communities rely on ecosystem services and everyday resources for their coping strategies (Shackleton and Shackleton 2004) but they do not develop any management strategies for these services and resources, mainly due to the lack of capacity and adequate governance structures. This could lead to increased ecosystem degradation and vulnerability in the long term. Proactive adaptive strategies that allow for social learning and flexibility in responding to environmental feedback are essential to promote long-term resilience for socio-ecological systems (Fabricius et al. 2007; Olsson, Folke, and Berkes 2004).

Planning adaptation

Due to the wide range of climatic contexts, ecological systems, and impacted sectors, there is no universal recipe for designing and implementing adaptation (Füssel 2007b). Smit et. al (1999) offer a number of considerations to take into account, shown in Table 4. In most cases, an effective adaptation strategy will require concerted and coordinated actions of almost all types listed: by individuals, collectives, and national governments; to address both short-term and long-term challenges; including capacity building for both responsive and anticipatory adaptation, etc. Consequently, for any given socioecological system, adaptation strategies cannot be imposed as blueprints, but must be tailored to the relevant local economic, environmental, political, and cultural context, and must target the appropriate institutions in order to have the needed impact at the necessary temporal and spatial scales (Locatelli et al. 2008).

Table 3. Different Types of Adaptation

Differentiating Concept	Types of Adaptation
Timing	<ul style="list-style-type: none"> – Anticipatory (or proactive) adaptation takes place before impacts of climate change are observed – Responsive (or reactive) adaptation takes place after impacts of climate change have been observed
Temporal scope	<ul style="list-style-type: none"> – Short term (or tactical) – Long term (or strategic)
Spatial scope	<ul style="list-style-type: none"> – Localized – Widespread
Actors	<ul style="list-style-type: none"> – Private adaptation: initiated and implemented by individuals, households, or private companies. Private adaptation is usually in the actor's rational self-interest. – Public adaptation: initiated and implemented by governments at all levels. Public adaptation is usually directed at collective needs.
Function or effects	– Retreat, accommodate, protect, prevent, tolerate, spread, change, restore
Form	– Structural, legal, institutional, regulatory, financial, technological

Source: Adapted from Smit et al. (1999).

Note: Definitions from IPCC (McCarthy et al. 2001).

Local and national stakeholder support

An effective adaptation strategy planning process should start with, and be framed by, vulnerability parameters of relevance to local stakeholders. This process will typically start with an investigation of existing strategies for dealing with climate variability and local stakeholder perceptions and understandings of the current and projected climate change and vulnerability contexts (Agrawal 2008).

In this context, local institutions should be considered as key actors in adaptation planning, building on their potential to efficiently detect vulnerability and define possible adaptation responses and outcomes. Furthermore, any adaptation activities (and changes in behaviors) require the active leadership of local leaders and institutions. Therefore, an extensive analysis of, and engagement with, formal and informal institutions is necessary in order to help ensure that the measures planned will be accepted by the community (Pelling and High 2005; Allen 2006). Any planned adaptation should aim to empower local stakeholders, particularly, those who may already be marginalized or more vulnerable (such as women, youth, and minorities) (Allen 2006).

Local relevance and ownership, however, might be insufficient for successful adaptation because local actions will generally require coordinated and supporting actions by relevant national institutions, and national policies and programs have a strong influence on local adaptive capacity.

Addressing current vulnerability but avoiding “maladaptation”

In many developing country contexts, there may be some difficulty in distinguishing between adaptation to climate change and what some observers would refer to as “development as usual.” This confusion is somewhat justified initially because, in many contexts, the current levels of vulnerability (given existing climate, market, and governance

conditions) must be addressed before stakeholders can hope to implement adaptation strategies focused on the potential impacts of long-term climate change. Therefore, reducing current vulnerability must be recognized as an essential first step in the process of adaptation to climate change. A society that is less vulnerable to current threats has the potential to be more adaptive to future changes (Locatelli et al. 2008).

Adaptation efforts can focus on responses to specific impacts (such as increased temperatures) or on reducing vulnerability by addressing underlying shortages of capability. Following the spectrum of adaptation activities delineated by the World Resources Institute (McGray, Hammill, and Bradley 2007), vulnerability-oriented efforts can overlap almost completely with traditional development practices (for example, diversification of livelihoods in flood-prone areas). Such activities generally aim at reducing poverty and addressing other fundamental shortages in capacities and assets that make people vulnerable to harm. Although most development practices do not actively take climate risks into account, they can lessen the negative impacts of climate change.

Ideally, vulnerability assessments and evaluation of impacts should reflect a comprehensive analysis at a range of temporal and spatial scales to avoid increased vulnerability in the future (Adger, Arnell, Tompkins 2005). "Maladaptive" strategies are those that may be successful at addressing livelihood, mitigation, or conservation objectives at a specific spatial or temporal scale, but which have negative impacts at other scales of analysis. These may include strategies which (Barnett and O'Neill 2010):

- increase emissions of greenhouse gases,
- disproportionately burden the most vulnerable,
- have high opportunity costs,
- reduce incentives to adapt, or
- create or reinforce path dependency (that is, limit the choices available to stakeholders in the future).

Mainstreaming adaptation into development

Due to the wide array of climate change impacts that are expected across the range of development and natural resource sectors, and because the most vulnerable segments of society tend to be more dependent on both natural resources and development programs than society at large, policymakers should aim to mainstream climate change adaptation into national policies and across all sectoral programs (Huq and Burton 2003; Lemos et al. 2007; UNFCCC 2007). In fact, Agrawal (2008) argues that development interventions that do not address climate change adaptation may worsen overall well-being. An additional benefit of mainstreaming climate change adaptation into national planning is that the need for adaptation may serve as a catalyst for the development and implementation of sustainable natural resource and development policies (UNFCCC 2007).

Climate change adaptation needs to be supported by an integrated, cross-cutting policy approach for several reasons:

- Climate change impacts cut across sectors and geographic and administrative boundaries.
- Vulnerability is frequently linked to poverty and marginalization in key natural resource governance institutions.
- Climate change is projected to significantly undermine development and progress made toward achieving the Millennium Development Goals (MDGs).
- Development choices can lead to maladaptation (for example, increase dependency on climate-sensitive resources) or be in conflict with adaptation priorities at different spatial and temporal scales.

4. Introducing the Ecosystem-Based Adaptation

The ecosystem-based adaptation (EBA) approach is gradually gaining popularity among adaptation, development, and conservation decision makers and practitioners. It has been recognized within the United Nations Framework Convention on Climate Change (UNFCCC), as demonstrated by its inclusion in several adaptation proposals submitted by countries and nongovernmental organizations (International Union for the Conservation of Nature 2008; Brazil, Costa Rica, Panama, and Sri Lanka in 2009). EBA encompasses adaptation strategies that explicitly value the roles of ecosystem services in reducing societal vulnerability to climate change across sectors and scales (Vignola et al. 2009). The basic argument for EBA concerning forests is as follows (Locatelli et al. 2010a):

1. Forest ecosystem services are important for a range of societal needs, and are critical for reducing vulnerability to climate change.
2. A reduction of these ecosystem services presents a threat to societal well-being now and increasingly within the context of climate change.
3. Therefore, forest conservation, restoration, and management need to become recognized as a valid and necessary adaptation strategy for this range of sectors.

EBA can be cost-effective and sustainable, and generate environmental, social, economic, and cultural benefits (CBD 2009). This is supported by the 2009 The Economics of Ecosystems and Biodiversity's cost-benefit analyses that concluded that public investment should support ecological infrastructure (forests, mangroves, wetlands, etc.) because of its contribution to adaptation to climate change (TEEB 2009).

4.1 What EBA implies for forest management

Ecosystem-based adaptation presents a number of challenges, because it requires an approach that integrates inputs and roles across scales and sectors (Tompkins and Adger 2004; Folke et al. 2005; Boyd 2008). For example, EBA requires the involvement of the sectors that manage ecosystems and of sectors that benefit from ecosystems services.

Nevertheless, climate change and other human-induced land cover changes present society with increasingly complex, interdisciplinary, and urgent challenges. This will necessitate the emergence of innovative cost-benefit sharing institutions, and adaptation strategies will need to be assessed on their effectiveness and efficiency and their cross-sectoral effects. For example, a downstream hydropower plant or a drinking water facility facing problems of siltation or water quality may be incentivized to invest in upper watershed forests.

In order for an EBA to be effective and sustainable, non-forest related sectors and downstream populations or institutions would be required to support forest management. Essentially, it will involve supporting forest managers and forest user communities in their contributions to the common good (that is, benefits that will go to other sectors or downstream populations) (Glück et al. 2009). Ideally, forest management agencies and local communities that bear the costs should receive financial transfers from the other sectors (or from local and national governmental institutions planning adaptation, conservation, or development programs).

To date, although there is growing awareness regarding the value of forest ecosystem services, adaptation policies and proposed projects have tended to apply sectoral approaches, and have limited the discussion related to vulnerability to that of forest communities, rather than society as a whole. Therefore, while forest-based adaptation strategies are included in the National Adaptation Programmes of Action (NAPAs, as described below), their scope

remains limited (Pramova et al., 2012b). This suggests critical gaps in, or the absence of, a science-policy dialogue (Locatelli et al. 2010). Additionally it must be recognized that EBA represents a significant challenge to most national governments' modes of operation, due to cross-sectoral cooperation difficulties and the need to work across administrative boundaries, and each ministry or department's interest in sourcing funding from central government treasuries.

4.2 Relevant international policy responses for ecosystem-based adaptation

Adaptation in international negotiations on climate

From the year 1992, when the UNFCCC was signed in Río de Janeiro, and up until the recent past, most of the convention's efforts were directed toward creating and implementing mitigation policies and measures. However, in 2001 the third IPCC report demonstrated that some degree of climate change is inevitable and for this reason adaptation will become a necessity (IPCC Third Assessment Report, 2001).

The political interest in adaptation to climate change evolved significantly after the 7th Conference of the Parties (COP 7) of the UNFCCC, held in 2001 in Marrakesh, with the resulting Marrakesh Accord highlighting adaptation as an important area of action (UNFCCC 2002).

Progress toward adaptation: NAPAs, funds, and work programs

During the COP 7, the establishment of the NAPAs for the least developed countries (LDCs) and of the Adaptation Fund were agreed upon. The Adaptation Fund, made operational in 2009, is a financial instrument under the UNFCCC and its Kyoto Protocol (KP), aiming to finance concrete adaptation projects and programs in developing countries that are parties to the KP. The Least Developed Countries Expert Group (LEG) and the Least Developed Countries Fund (LDCF) were established during the same COP 7 to support the preparation and implementation of the NAPAs and the general LDC work program (SBI UNFCCC, 2010).

Currently, adaptation to climate change is one of the main areas of discussion in the international climate change policy arena, within the Nairobi Work Program (NWP) and the establishment of the Cancún Adaptation Framework during UNFCCC COP 16 2010, constituting the first global agreement on adaptation, which launches a clear working program and Adaptation Committee and defines adaptation finance as new and additional to existing aid commitments. The framework outlines the principles under which adaptation action should occur, such as transparency, stakeholder participation, gender sensitivity, consideration of vulnerable groups and ecosystems, use of indigenous knowledge and best available science, and the integration of adaptation into relevant social, economic, and environmental policies and actions (Pramova and Locatelli, 2011).

As far as the role of forests is concerned, a key point of the Cancún Adaptation Framework is the inclusion of both ecosystems and communities in its guiding principles and priorities, recognizing the need to build and sustain natural ecosystem resilience. However, there is no acknowledgment of the link between social and ecological resilience or of the potential of ecosystems such as forests to provide ecosystem services for adaptation (Pramova and Locatelli 2011).

Ecosystem-based approach in the negotiations

The ecosystem-based approach has been suggested as a strategy for the “integrated management of land, water and living resources that promotes sustainable development and conservation of these resources” (UNFCCC 2010, p. 36). This approach is judged to be “useful as it can take into account direct and indirect impacts as well as the

effects of adaptation measures” (UNFCCC 2010, p. 36). Methods and tools from the Convention on Biological Diversity related to the ecosystem approach are also highlighted as well as the importance of ecosystem assessments for the evaluation of potential contributors to the vulnerability of communities and their livelihoods.

Several countries that are parties to the UNFCCC have submitted proposals and negotiating texts to advance the consideration and implementation of the ecosystem approach in adaptation. One such proposal is included in the negotiating text of Costa Rica, submitted to the Ad Hoc Working Group on Long-term Cooperative Action under the Convention (AWG-LCA) for its fifth session held from March 29 to April 8, 2009.

Costa Rica called for the inclusion of vulnerability assessments for ecosystems, ecosystem services, and the livelihoods that depend on them as essential parts of overall risk reduction plans. The country also advocated for considering EBA in sectoral and national planning for disaster risk reduction and management and for the evaluation of the general implications of adaptation strategies for ecosystem services on which people depend.⁴ Uruguay's submission highlighted that it is critical for the convention to address the importance of ecosystem resilience and that adaptation strategies for the implications of climate change on ecosystems should be an essential part of the adaptation framework.⁵

5. Forests and Adaptation

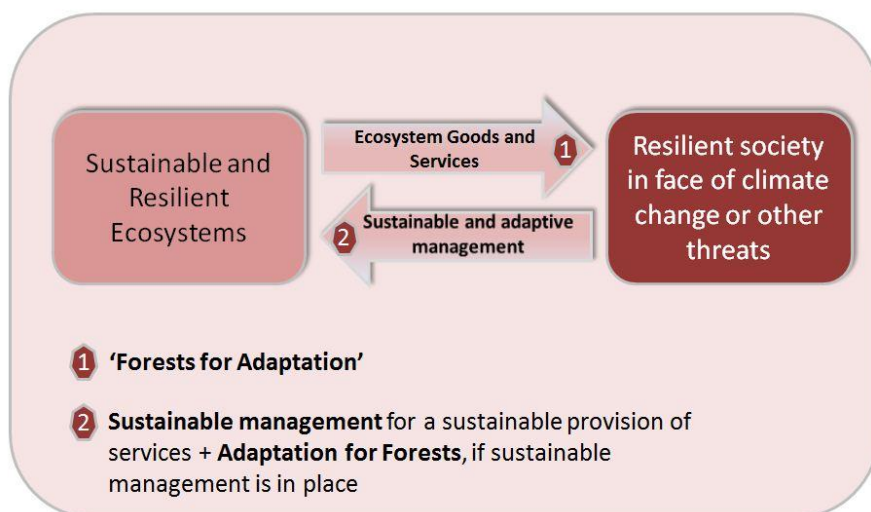
5.1 Understanding the links between forests and adaptation

Within the context of forestry and sectors benefiting from forest ecosystem services, climate change adaptation has two key dimensions that need to be addressed to ensure effectiveness (Locatelli et al. 2010a). First, forest ecosystems provide human societies with a wide range of ecosystem services that reduce at the local and sectoral levels the vulnerability to impacts of climate change (particularly changes in the frequency, duration, and intensity of temperature, rainfall, coastal flooding, and hurricanes). However, these climate change variables will also have significant impacts on forest growth, species diversity, and ecosystem function. Therefore, in order for human society to continue to benefit from forest ecosystem services, adaptation strategies must also reduce the negative climate change impacts on forests themselves. These two roles for adaptation can be summarized as “adaptation for forests” and “forests for adaptation,” and are illustrated in Figure 4.

⁴ Draft negotiating text submitted by Costa Rica on Adaptation for the fifth session of the AWG-LCA: http://unfccc.int/files/meetings/ad_hoc_working_groups/lca/application/pdf/costarica_adaptation230409.pdf (last accessed April 12, 2010).

⁵ Submission by Uruguay on Adaptation for the fifth session of the AWG-LCA: http://unfccc.int/files/meetings/ad_hoc_working_groups/lca/application/pdf/uruguayadaptation240409.pdf (last accessed April 12, 2010).

Figure 4. Forests for Adaptation, Adaptation for Forests



Source: Locatelli, 2011.

5.2 How ecosystem services help societies to adapt

Forests provide valuable and, in some contexts, critical goods and services that reduce vulnerability of human societies to the impacts of climate change at local, landscape, regional, and global scales. These ecosystem services have been classified by the Millennium Ecosystem Assessment (2003) into the following categories:

- *provisioning services*, also called ecosystem goods, such as non-timber forest products (NTFPs), food, and fuel;
- *regulating services*, such as regulation of water, climate, or erosion;
- *cultural services*, such as recreational, spiritual, or religious services; and
- *supporting services* that are necessary for the production of other services, such as primary production, nutrient cycling, and soil formation.

As mentioned above, many rural communities rely on ecosystem services and everyday resources for their coping strategies (Shackleton and Shackleton 2004). To capture the role of ecosystem services from forests in adaptation, this section provides illustrations of how these services help reduce exposure, reduce sensitivity, and increase adaptive capacity. It does so by looking first at the impact of climate change on a few key sectors and livelihood and then presenting how the ecosystem services from forests help reduce vulnerability.

Ecosystem provisioning services

Overall, ecosystem goods derived from forests can be directly linked to the basic requirements for good quality of life for many communities in developing countries (that is, income, food security, shelter, and health) (Levy, Babu, and Hamilton 2005; Colfer et al. 2006; Colfer 2008). The goods from forests help households to diversify their livelihood portfolio. The importance of forest products, as an additional source of income and nutrients, is more pronounced when households are faced with climate-related variability. Provisioning services from forests assist households in the rural and agricultural sector to reduce their vulnerability to climate change.

Using forest resources to cope with climate variability

Recent studies have indicated that rural populations in developing countries receive on average roughly 25 percent of their income from harvesting non-timber forest products (including, shoots, roots, mushrooms, wildlife, insects), with such activities being particularly critical income-generating opportunities for women-led households in many poor rural areas (see special issue of *Tropical Forestry* titled “Non-Timber Forest Products in a Global Context” (Shackleton, Shackleton, and Shanley 2011). These studies underscore the critical roles that non-timber forest products play in the overall livelihood strategies of local populations. In some countries, this proportion is much higher; for example, in Laos NTFPs are estimated to provide roughly 40 percent of household income nationally, with this figure rising to 90 percent among the rural poor (UNDP 2001). Overall, ecosystem goods derived from forests can be directly linked to the basic requirements for good quality of life for many communities in developing countries (that is, income, food security, shelter, and health) (Levy, Babu, and Hamilton 2005; Colfer et al. 2006; Colfer 2008).

Additionally, many rural communities in developing countries rely to a significant degree on timber and charcoal resources as key sources of income (through either direct sale or salaried labor) and as particularly valuable means for recuperating the loss of productive capital following livelihood shocks.

Two studies in Tanzania document the critical roles that forest goods have in providing for the needs of poor rural households during years when harvests fail (Enfors and Gordon 2008; Paavola 2008). Indeed, during the drought years of 2005–06, 85 percent of interviewed households indicated their reliance on forest provisioning services (particularly, wild fruits and firewood), which was estimated to provide 42 percent of the total income during these years (Enfors and Gordon 2008). This made forest goods roughly as important as the combined income from short-term wage labor, remittances, and off-farm employment. It should also be mentioned that because charcoal production was illegal, based on qualitative interview data, these estimates were judged to vastly underrepresent the critical roles of forest products overall. Similarly, for rural households in Malawi, forest products have been shown as key sources of food and income during years of crop failure (Fisher et al. 2010).

Forest products are an important safety net in Central and South America as well, particularly following extreme events such as hurricanes and floods. In Honduras, poor rural households sold forest products to self-insure after being unable to recoup land holdings that were lost due to Hurricane Mitch. Household attributes such as land wealth strongly condition how and when forest resources act as safety nets for the rural poor, especially for the relatively subsistence-insecure (McSweeney 2005).

In Peru, NTFP gathering (such as fruits and palm hearts), was identified as important for coping with crop failures due to flooding. This was particularly important among younger and poorer households, and those lacking upland farm plots or rich fish stocks nearby. Clear links exist between asset poverty and NTFP gathering as insurance in certain locations, with NTFPs being the last-resort option for the most vulnerable households (Takasaki et al. 2004).

Intensifying forest/tree management to reduce vulnerability

In Niger, farmer-managed natural regeneration of valuable indigenous tree species on private lands has significantly increased the income and resilience of farmers during years of drought (Tougiani et al. 2009). Building upon local ecological knowledge, through the development of village committees and the establishment of rural wood markets, local stakeholders have been able to improve regulation of local tree harvesting and reduce exploitation by intermediary traders.

In Batu Ampar, Indonesia, diminishing terrestrial timber supplies during the early 2000s resulted in increasing demand and prices for charcoal. Recognizing the increased pressure on local mangroves, forest rangers and NGOs

encouraged local communities to develop local rules regulating the technologies used to cut down mangroves (that is, use of axes rather than chainsaws), as well as restricting which areas could be logged in order to prevent their conversion for aquaculture (banning logging within 50 meters of the outer margin) (Prasetiamartati et al., 2008).

Elite capture of income from valuable forest products

Research by numerous authors has highlighted how external interests or local elites have a tendency to capture a disproportionate share of the benefits from the sale of NTFPs once their value is recognized, or once infrastructural development facilitates traders' access to previously remote communities (Pandey et al., 2007). To illustrate, Dove (1993) documents the Indonesian examples of latex and rattan, where internal or external elites capture of benefits from NTFPs once it becomes apparent that money can be made from them, such as the. Similarly, Nkem et al., (2010) documented how the distribution of market revenue from the sale of many NTFPs in the Congo basin leaves rural stakeholder with a minimal share of retail forest product value, while wholesalers and retailers reap most of the benefits. In the case of the marketing of fish from forested areas of the Congo basin, Russell et al (2007a,b) found this to be caused by a combination of traders' and elites networks in urban markets and greater access to capital which enabled them to overcome the barriers of rent-seeking behavior by civil servants.

Therefore, it must be understood that markets may increase the value of the commodity, but seems their contribution to the adaptation of local communities may be limited as the distribution of benefits is unequal. Markets should be regarded as complimenting, rather than substituting, the direct roles of forests for adaptation.

Ecosystem regulating services

Though more difficult to measure, forest regulating services are critical to society at large. All forest types contribute to microclimate regulation and stabilization, sediment retention and nutrient detention, important services for both the resilience of adjacent ecosystems and of agriculture. Furthermore, forests help to buffer society from the brunt of many natural disasters by preventing landslides, moderating the force of waves or wind during storms (Adger, Brown, and Tompkins 2005), and reducing temperatures during heat waves (Gill et al. 2007). In Central America, for example, climate change predictions of increased rainfall intensity are causing concern about erosion and siltation among hydroelectricity companies, and they are considering upstream watershed forest conservation as a critical measure to adapt to climate change (Vignola and Calvo 2008).

The following discussion builds on an analysis by Pramova et al. (2012a) of the relationship of forests and trees to regulating services for agriculture, water, and security, focusing on four major forest categories: upland forests, riverine/floodplain forests, agro-forested landscapes, and coastal mangroves.

Restoring land using trees to increase adaptive capacity

In Kenya, the Regional Development Authorities are implementing catchment conservation programs covering vast areas in the country to promote practices that, among other things, address soil erosion and water loss. One of the interesting approaches was the “fanya juu” and the cutting of drains that was adopted in dry parts of the Machakos, Majueni, and Kitui districts.⁶ Because of their success in areas that otherwise would be bare lands, these practices are therefore spreading to other areas of the country. In Machakos for instance, crop yields have increased by 50 percent (or by 400 kg/ha) through the use of fanya juu terraces.

⁶ Fanya juu terraces are constructed by digging a contour trench and moving the soil to the upper part of the trench in order to form an embankment on which to plant fruit trees, Napier grass, or others. The trench traps and holds water that is gradually released to the farmland. The labour required for construction is estimated at 150 to 350 person days/hectare for terraces and cutoff drains. The cost of these structures is approximately US\$60–460/hectare.

In Mali and Niger, for the past 30 years, the loss of natural vegetation reduced the arid zone ecosystems' resilience to recurrent droughts. As a consequence, local people face famine, poverty, and migration. In an already drought-afflicted region, additional climatic stresses are expected to be detrimental to food security and development. International donor assistance has been provided to these countries to finance reforestation of more than 23,000 hectares of *Acacia senegalensis*, a species native to the African Sahel, on communal degraded land throughout Mali and Niger. Planting of this native species is expected to restore habitat for native fauna and projected to sequester approximately 0.3 Mt CO₂e (metric tons of CO₂ equivalents) by 2017 and 0.8 Mt CO₂e by 2035 in Mali, and 0.24 Mt CO₂e by 2012 and about 0.82 Mt CO₂e by 2017 in Niger. The rehabilitation of degraded land, improves soil fertility, creates jobs, and increases local incomes through sales of high-quality Arabic gum and payments from Credit Emission Reductions (CERs) (Tahia 2010).

Upland forests and watersheds

A limited number of studies suggest that forested landscapes may increase local base stream flow levels while reducing storm run-off (Ilstedt et al. 2007; Locatelli and Vignola 2009; Pattanayak and Kramer 2001). This has the particular benefit of buffering agricultural production from the impacts of periodic interruptions in seasonal rainfall, and reducing the danger to agricultural production and to peoples' safety from flooding. Pattanayak and Kramer (2001) found that even relatively small increases in base flow have the potential to translate into sizable economic benefits for agricultural production.

These promising results are confounded by other studies, however. A meta-analysis of watershed services, provided by limited studies in humid natural forests versus planted forests in Central America, indicates, however, that planting does not provide these same hydrological services (Locatelli and Vignola 2009). This may be determined to a certain degree by the age and stand structure of plantings as well as logging/burning practices that affect the soil itself (Kaimowitz 2005). Additionally, in the case of intense and persistent rainfall, increased tree cover has actually been shown to be correlated with increased flooding, possibly due to vegetation limiting the infiltration of rain into the soil (Bruijnzeel et al. 2004; Scott et al. 2004; Liu et al. 2011). Finally, studies on soil erosion find that soil coverage (understory vegetation and litter layer) may have more influence on the rate of soil erosion than tree cover does (Scott et al. 2004; Goller et al. 2005).

Given the research summarized here, the levels of certainty with regard to potential benefits from upland forest ecosystem services are at times overrepresented in the development of payment-for-ecosystem services schemes (FAO 2004). Increasingly, scientists are concluding that forest impacts on regulatory services are highly dependent on site-specific conditions, such as tree species, topography, geology, soil type and condition, and issues of scale (Pramova et al. 2012a). They do conclude, however, that natural forest should be seen as the natural baseline for erosion control against which all other land uses should be compared, and that reforestation cannot be expected to reverse the damage deforestation induces on the delivery of ecosystem services in the short or medium term (Calder 2002).

In Costa Rica, efforts to reduce sedimentation of a hydropower dam, however, found that using reforestation or soil conservation measures in erosion hotspots made economic sense. Erosion affects hydropower dams by increasing the costs for companies to extend the life span of the dams. It also impacts the life span of hydropower dams themselves. In the Birris watershed of Costa Rica, the lifespan of a hydropower dam depends on the quality of water reaching it, which is determined by sediment loads flowing down the watershed. Indeed each year, up to one and a half million tons of sediment loads are removed from the dams to ensure the longest possible life span. More than US\$2 million is spent to partially remove these sediments and to produce energy by alternative sources during this

operation. A study exploring different measures for controlling soil erosion and continuing with business as usual in the Birris watershed found that reforestation or soil conservation practices in high-risk areas for erosion brought about significant reduction in erosion. However, reforestation of high-risk areas could be done at a lower cost and offer greater net benefits (Bruce, et al. n.d).⁷

In Kenya, a rapid assessment of the impact of climate change on hydropower generation under minimum and maximum climate change projections in the Tana river basin showed that the impact of climate change without adaptation strategies ranges from a positive US\$2 million to a cost of US\$66 million for the hydropower, irrigation, and drinking water sector. However, when costs and benefits of various adaptation strategies are accounted for, the measures result in positive outcomes ranging from US\$11 million to US\$29 million for the low and high climate change projections, respectively. The study compared adoption of infrastructure-based and ecosystem-based adaptation measures and found that the ecosystem-based adaptation measures were profitable only if the climate trends in the direction of the more significant temperature changes (Peter et al. 2009).

Riverine and floodplain forests

The regulatory services of riverine and floodplain forests, particularly in flood control, are quite different from those of upland forests. Their main function is to delay the passage of flood waters by causing water to meander through circuitous side branches, where physical resistance from vegetation and meandering river banks physically slows down the movement of water (Anderson 2008). This gives downstream waters more time to subside. The increased risk of flooding in areas downstream from agricultural or non-forested floodplains is widely recognized as being higher than flooding downstream from forested floodplains (Bates et al. 2008). Due to the tendency for countries to build levees or channel rivers as part of urbanization, and the fact that most societies disproportionately develop their major centers of habitation and industry in floodplains, the impacts of flooding on floodplains under extreme climate events may be expected to increase (Tockner and Stanford 2002; Ebert 2010).

Trees in agro-forested landscapes

A substantial body of research has produced evidence on the benefits of agro-forestry (mainly on transfer of nutrients between trees and crops). Although most studies do not draw a link between specific agro-forestry systems (tree species and crop types) and climate hazards, a few well-documented exceptions are worth highlighting.

Long-term research has shown that fertilizer tree systems (using nitrogen-fixing trees such as *Faidherbia albida*), when intercropped with maize, contribute to increased drought resilience of maize due to the combined effects of improved soil nutrient levels and increased water infiltration into the soil (Garritty et al. 2010). This research on *F. albida* is supported by widespread indigenous knowledge among farmers in Africa regarding the benefits of this tree (among others) through nitrogen fixation and the supply of fodder (Tougiani et al. 2009).

With respect to key cash crops, recent studies have documented the contributions of shade trees to protecting coffee agriculture from climate variability and climate extremes. Specifically, based on research in high-, medium-, and low-shade coffee sites in Central America, Lin (2007 and 2010) found that shade trees have a positive influence on the

⁷ It should be noted that while the study pointed to the optimal approach, the preference of the stakeholders was not for the best alternative from an erosion-control perspective (i.e., reforestation of high-risk areas). Stakeholders preferred adopting soil conservation practices in high-risk areas (i.e., a mix of activities, from increasing tree cover to improved soil management practices in agricultural plots), which brought a convergence of benefits to hydropower and farmers. This approach avoided the large cost to target soil conservation all over the watershed yet significantly improves the provision of on-site and off-site benefits of erosion control. At the same time, the approach allowed farmers to avoid drastic land-use change and maintain their agricultural livelihood, thereby preserving the economic, social, and cultural paradigms of local communities.

intensity of fluctuations in temperature, humidity, solar radiation, and soil moisture, all climatic variables to which coffee crops are extremely sensitive.

These studies suggest that in some contexts agro-forested approaches may be more successful than agricultural intensification in addressing some of the climate change threats to society's agricultural systems (Lin et al. 2008). Furthermore, Verchot et al. (2007) found that more diversified farming systems suffer less from climate shocks when measured over the long term. These conclusions are supported by Venema (1996), which used a water resources simulation model to demonstrate that a natural resources management policy could bring larger areas under agricultural production with less water and also enhance the sustainability of food production.

Coastal forests and wetlands

A number of studies have associated the regulating services of coastal wetlands such as mangroves with protection against cyclones and other storms in Asia and Southeast Asia (Alongi 2007; Badola and Hussain 2005; Das and Vincent 2009; Danielson et al. 2005; Tri et al. 1998). As in the case of floodplain forests, mangroves regulate primarily by creating a physical barrier to wave action, stabilizing the sea floor, and altering the slope of the sea flood.

Badola and Hussain (2005) compared the impacts of cyclones in villages protected by mangroves, villages lacking mangroves, and others protected by an embankment. They found that the mangrove-protected village had the lowest amount of adverse effects (such as damage to homes) and the highest beneficial values (such as crop yields). Apparently, the village protected by an embankment was worst affected by the cyclone. Similarly, Tallis et al. (2008) found that potential damage from storms, coastal and inland flooding, and landslides can be considerably reduced by a combination of careful land use planning and maintaining or restoring ecosystems to enhance buffering capacity. In Vietnam, they found that planting and protecting nearly 12,000 hectares of mangroves cost US\$1.1 million but saved annual expenditures on dyke maintenance of US\$7.3 million.

In 1999, the state of Orissa in India was battered by a super cyclone that killed almost 10,000 people and caused a massive loss of livestock (440,000 livestock deaths) and property (almost 2 million damaged houses and over 1.8 million hectares of damaged crops). In all, 12 districts in the state were devastated by the cyclone. Das (2007) examined the role of mangroves alongside all the other factors that affected the impact of the storm in one of the districts that had significant mangrove loss in the past. When the storm hit in 1999, only about 50 percent of the original mangroves remained. The study established that mangrove forests could have significantly reduced the number of human casualties from the super cyclone. For instance, if the mangrove forests that had existed in 1950 were still in place, 92 percent of the deaths would have been avoided. If the 1999 mangrove forests had not been there, the death toll would have been 54 percent higher than it actually was. The mangroves were also able to significantly lower the degree of house damage in areas within 10 kilometers of the coast and contributed to reductions in the death of large livestock—even though they were less effective in protecting smaller animals like goats and poultry. Das (2007) also estimated that a hectare of mangrove forestland stopped damage worth US\$43,352 in the district during the super cyclone. It also established that the value of a hectare of land with intact mangrove forests was US\$8,670, whereas a hectare of land after mangroves are cleared sold at US\$5,000 in the market at that time. Further, the cost of regenerating one hectare of mangroves was approximately US\$110—many times lower than the benefits that would occur (US\$8,670). Also, the cost of constructing a cyclone shelter would have been roughly 10 times more than the benefit offered by mangroves.

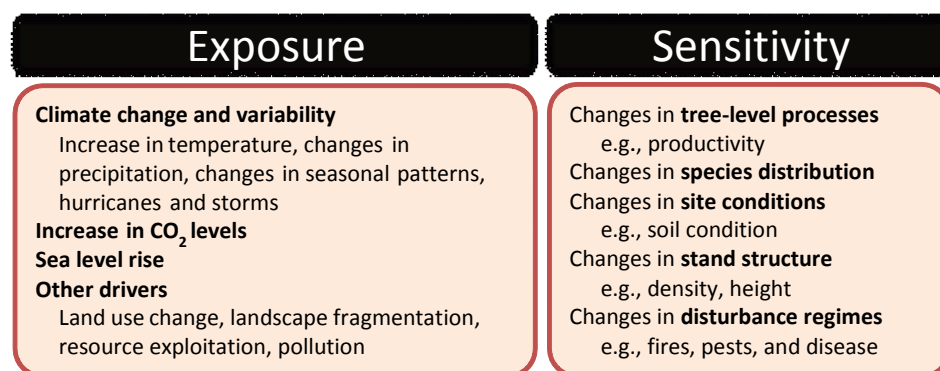
One area of misconception relates to the overconfidence that mangroves can protect coastal societies during extreme events in the context of predicted sea level rise. Consequently, mangrove conservation and restoration may in many cases need to be paired with other adaptive strategies such as relocation of human settlements to higher

ground. Overall, any mangrove conservation or coastal zone planning can rely on the wider contributions to coastal livelihoods that mangroves make (NTFPs for food security, fish habitats, regulation of salinization, protection of biodiversity), in order to convince coastal communities to regard it as a “no-regrets” policy (Mustelin et al. 2010)

5.3 Why we should take adaptation for forests seriously

The impacts of climate change on forests will vary widely between countries and regions, and these impacts will be compounded by other society-induced drivers of change (for example, land-use change, pollution, overexploitation of resources) (Locatelli et al. 2010a). Some change-inducing factors of exposure and of forest sensitivity are presented in Figure 6.

Figure 5. Components of the Exposure and Sensitivity of Forest Ecosystems



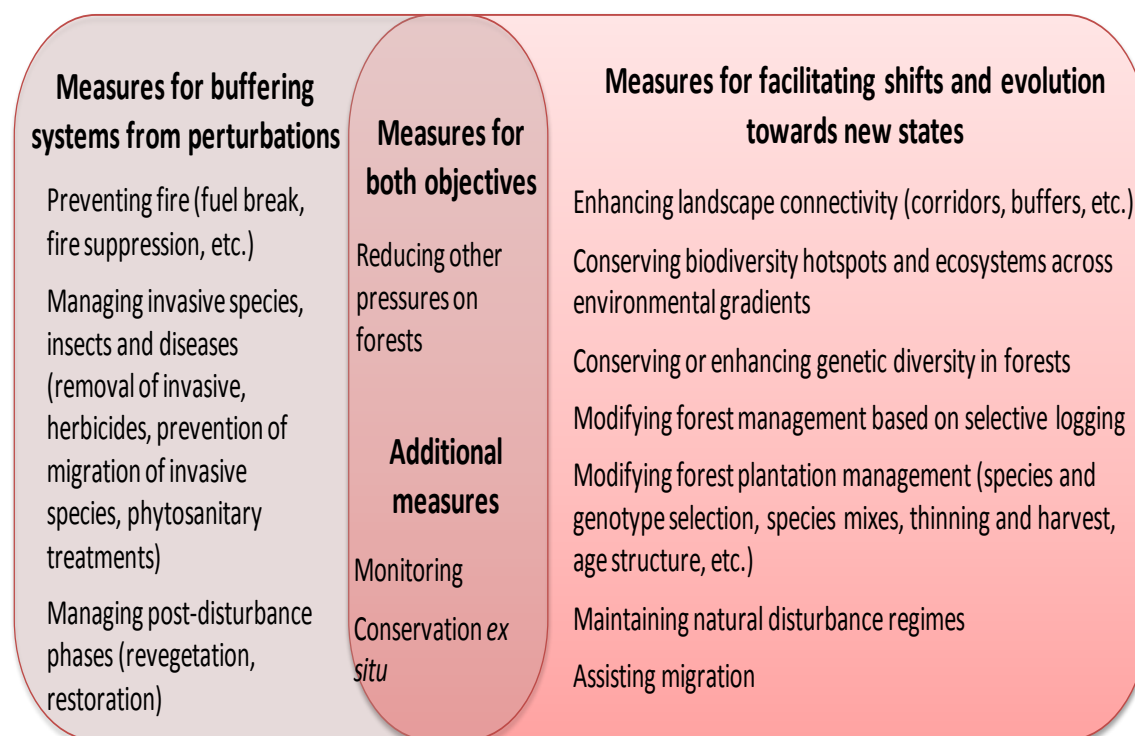
Source: Johnston and Williamson (2007).

Although the adaptive capacity of forests remains uncertain (Julius et al. 2008), many scientists are concerned that this innate capacity will be insufficient for forests to adapt to unprecedented rates of climatic changes (Gitay et al. 2002; Seppala, Buck, and Katila 2009). The impacts of climate variability and change on tropical forests ecosystem structure and functioning and on carbon cycling are already being documented (Root et al. 2003; Fearnside 2004; Malhi and Phillips 2004). The impacts in three major forest types are as follows:

- **Humid tropical forests** in Indonesia and Brazil are experiencing increased droughts and frequencies of forest fire, and there is some concern that this might contribute to a large-scale conversion of tropical rainforest to savannah in the Amazon (Barlow and Peres 2004, Murdiyarso and Lebel 2007; Cox et al. 2004; Scholze et al. 2006; Nepstad et al. 2008). Adaptive capacity (through migration and colonization of new areas) will be diminished through forest fragmentation and the spread of invasive exotic vegetation (Nepstad et al. 2008; Fischlin et al. 2007).
- **Tropical dry forests** are particularly sensitive to small changes in precipitation, because this exposes the landscape to greater desiccation and increases the risk from forest fires (Hulme 2005; Miles 2006; Mwakifwamba and Mwakasonda 2001; Enquist 2002).
- **Tropical mangrove forests** are underappreciated and have been severely reduced due to conversion of coastal zones for tourism, infrastructure, and aquaculture development. In order to survive the predicted sea level rises, mangroves require increased amounts of sediment accumulation from inland watersheds in order to counteract coastal erosion, or they need space to migrate inland. Due to coastal development, the space for migration is limited, and sea levels are expected to rise at about twice the rate of sediment accumulation (Hansen et al. 2003).

Two broad approaches are possible for adapting forests: buffering the system from climate change impacts by increasing its resistance, and facilitating a shift or an evolution of the system toward a new state that meets altered conditions (see Figure 7). However, measures that attempt to keep forests in their current state may be effective only over the short term, and are likely to be associated with high costs due to the intensive management required for implementation, frequently leading to increased vulnerability in the long term. Consequently, these measures are recommended for only high-value forests (for example, high-priority conservation forests for biodiversity) or for forests with low sensitivity to climate change (Millar, Stephenson, and Stephens 2007). Of critical utility are those actions that may contribute to both buffering and long-term resilience, such as reducing forest conversion, fragmentation, and degradation (Noss 2001; Hansen et al. 2003; Malhi et al. 2008). In many tropical ecosystems, the urgency of addressing non-climatic threats by far outweighs the climatic ones (Markham 1996). Uncertainties about climate change and forest vulnerability highlight the need for flexible and diverse approaches that permit changes in the future (Millar, Stephenson, and Stephens 2007).

Figure 6. Examples of Technical Measures for Forest Adaptation



Source: Locatelli et al. (2008).

6. Conclusions and way forward

Declining productivity, declining water availability, and increased risk of disasters are the trends that existing climate models point to at a very macro level. The immediate need is to be able to adapt to these imminent and ongoing changes. But this has to happen at a time when public financial resources are limited and the most affected households are not well positioned to adapt on their own.

Forests can help societies adapt to climate variability and change.

Climate change impacts are already threatening to stall and even reverse development trajectories in many developing country settings, leading to an urgent need for efficient and sustainable adaptation. Currently, the net present value of climate change impacts in the absence of adaptation measures is estimated at US\$1240 trillion (CBD 2010a), while the UNFCCC (2007) estimates the cost of adaptation in agriculture, coastal zone, forestry, fisheries, health, infrastructure, and water supply sectors combined could reach US\$44 billion to US\$166 billion per year by 2030 for the world as a whole, and US\$28 billion to US\$67 billion for developing countries. While the estimates of costs and benefits of adaptation are wide-ranging, they all point to the urgency of adaptation. They also point to the need to think through how we do adaptation and do it in a way with multiple gains.

A secure flow of forest ecosystem goods and services has the potential to significantly aid societal adaptation to climate change. Mangroves can protect coastal areas against storms and waves, which are predicted to become even more intense with climate change and climate-induced sea level rise. Forest products can provide safety nets to local communities when climate variability causes crop failures, and urban forests can reduce temperatures during heat waves.

Forest ecosystems not only have the potential to reduce the vulnerability of communities to climate vagaries by protecting settlements and enhancing livelihoods and food security, but they can also play an important role for the adaptation of national economic sectors. The hydroelectric sectors of Costa Rica and Nicaragua, for example, which are crucial for the sustainable development of the two countries, are directly dependent on hydrological forest ecosystem services such as the regulation of water quantity and the reduction in soil erosion and sedimentation (Locatelli et al. 2010b).

Conversely, degraded forests and insecure flows of forest ecosystem services can make communities and sectors more vulnerable to climate variability and change and lead to increased adaptation costs. For instance, extensive deforestation around Malaysia's capital, Kuala Lumpur, coupled with recurring dry conditions, led to strict water rationing in 1998 and ultimately to costly imports of water (CBD 2010a). In Haiti, Hurricane Jeanne caused an estimated 3,000 deaths from torrential rainfall flooding, due in part to the country's highly deforested and degraded watersheds (World Bank 2009).

Ultimately, use of forests can foster an integrated approach to adaptation and mitigation and maximize the benefits achieved in addressing climate change (Locatelli et al. 2011). For example, agro-forestry activities eligible under the Clean Development Mechanism (CDM) can also be managed for the reduction of community vulnerability through erosion control and crop protection. Likewise, mechanisms such as REDD+ could (depending on their design and implementation) contribute to adaptation by improving local livelihoods, strengthening local institutions, and conserving ecosystem services (Angelsen et al 2012).

Using forests for adaptation requires a supportive institutional context.

Mainstreaming forests into adaptation policies requires cross-scale and cross-sectoral approaches as ecosystem benefits and management costs generally occur in different locations and impact different sectors of society. However, the sectors that depend on forest ecosystem services are rarely incentivized to get involved in forest-based adaptation and this leads to missed opportunities for inter-sectoral planning and financing of forest conservation, restoration, and sustainable management. Hydropower or drinking water facilities facing problems of siltation or water quality, for example, could be encouraged to invest in upstream forest management instead of opting for more costly measures, such as technical filtration and treatment or infrastructure.

Policymakers should create an environment that links ecosystem managers and vulnerable sectors that benefit from ecosystem services. Incentive-based policy instruments like payments for ecosystem services can be one way to achieve positive results, contributing to the adaptation of both forests and users of forest ecosystem services.

Policies should also encourage strategies that aid the adaptation of the forest ecosystems themselves in order to ensure the role of these ecosystems for social adaptation. Forest ecosystem resilience is a key issue that needs to be considered across scales because it can be undermined by a diverse range of anthropogenic, environmental, and climatic factors, and forests themselves are highly vulnerable to climate change.

Adaptation measures for forests can aim to buffer the ecosystems from disruptions, by increasing their resistance and resilience. They can also focus on facilitating forest ecosystem shift toward a new desired state, while maintaining forest structure, function, and ability to provide critical services. Adaptive management that responds to environmental and other feedback is crucial for forest ecosystems to adapt effectively to climate change. Adaptive management is also important for social adaptation, because climate change is highly likely to alter the form, scale, location, and distribution of forest ecosystem services

On national and subnational levels, it is crucial to map, model, and evaluate the multiple flows of forest ecosystem goods and services to the diverse users that depend on them. The analysis of important ecosystem services and identification of stakeholders can provide a better understanding of vulnerability, as well as important clues on the potential winners and losers of specific changes in socioecological systems due to climate change. Such exercises can also help identify priority areas for forest conservation and restoration and develop spatially targeted policies for forest management involving key users of ecosystem services.

It is important to make sure that forest-based adaptation strategies generate benefits in the short term that help cope with climate variability. Immediate benefits can help minimize the threat of forests being negatively affected by short-term and short-sighted coping strategies. This also points to the urgency of providing evidence to governments of these immediate benefits (or possible costs of forest degradation), and the need to complement that with putting in place the institutional fabric and technical support for proactive adaptation strategies and cross-sectoral coordination.

Effective local institutions, as well as national and subnational institutions, are central in facilitating the use of trees and forests in adaptation and promoting an intersectoral approach. The promotion of forest-based adaptation will, therefore, have to be accompanied by efforts to promote better governance (for example, secure tenure rights and local access to forests goods and services). This will require using innovative and practical approaches and institutional measures to foster tree- and forest- based adaptation.

It should be made clear that forest adaptation strategies should not be implemented at the expense of forest-dependent people through command-and-control measures, and that there is much that can yet be learned from peoples' existing livelihood strategies and coping mechanisms. Adaptation strategies should build on local knowledge, seeking to understand how policy and socio-economic incentives interact with environmental and climatic conditions to shape locally-attuned livelihood strategies, and should aim to integrate local coping needs with broader conservation and climate change adaptation objectives.

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